NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

# REPORT OF TEST RESULTS

REPORT NO: NAWCADPAX/RTR-2000/191

# F/A-18A/B/C/D MAIN LANDING GEAR CONTROL UNIT HYDRAULIC 2A SUPPLY LINE PRESSURE SPIKES AND EMERGENCY PORT RESTRICTOR GROUND AND FLIGHT TESTS EVALUATION

**by**

**Ms. Mary Picard**

**17 November 2002**

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DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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**RELEASED BY**:

Christopher M. Clark 17 Nov 2002
CHRISTOPHER M. CLARK / 4.11D / DATE
By direction of the Head,
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Research and Engineering Group

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| 17 November 2002 | Report of Test Results | 12 September 2000 - 28 March 2001 |

4. TITLE AND SUBTITLE

F/A-18A/B/C/D Main Landing Gear Control Unit Hydraulic 2A Supply Line Pressure Spikes and Emergency Port Restrictor Ground and Flight Tests Evaluation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Ms. Mary Picard

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Patuxent River, Maryland 20670-1161

8. PERFORMING ORGANIZATION REPORT NUMBER

NAWCADPAX/RTR-2000/191

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Air Systems Command
47123 Buse Road Unit IPT
Patuxent River, Maryland 20670-1547

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The F/A-18A-D fleet has been experiencing cracked brackets on the right main landing gear (MLG) wheel well hydraulic 2A (HYD 2A) pressure supply line. Investigations revealed that hydraulic pressure spikes in the HYD 2A supply line may be a contributing factor to the bracket failure. Some bracket failures have led to HYD 2A supply line failures. F/A-18E/F testing determined that landing gear circuit breaker resets and improper gear retractions following an emergency gear extension caused pressure spikes. A suspected but unproven cause of pressure spikes is the first engine start of the day. For this test, a production F/A-18A-D landing gear control unit (LGCU) was modified at NADEP North Island to accept a restrictor within the emergency port of the valve. The Boeing and Northrop Grumman developed restrictors were designed to control emergency spool movement and eliminate pressure spikes in the HYD 2A supply line. Three restrictors were designed with increasing levels of restriction (2000, 5500, and 9000 lohm). The elimination of pressure spikes is expected to reduce or eliminate the hydraulic line bracket failures that have been occurring in the USN/USMC fleet and FMS aircraft.

The purpose of this test was to investigate causes of pressure spikes in the HYD 2A supply line and evaluate the use of a restrictor in the MLG control unit of the F/A-18A-D aircraft. The entire evaluation consisted of three phases of ground tests and one phase of piggyback flight test and took place from 12 September 2000 through 28 March 2001. The 2000 lohm restrictor installed in the MLGCU effectively eliminated large magnitude pressure and vibration oscillations during an improper gear retraction while not adversely affecting landing gear times. Recommend using the 2000 lohm restrictor in both the NLGCU and MLGCU to control pressure oscillations in the emergency and HYD 2A lines while reducing the number of different configuration LGCU's.

15. SUBJECT TERMS

main, nose, landing gear, restrictor, lohm, HYD 2A, hydraulic, circuit breaker reset, improper gear retraction, extension, test cable

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | Ms. Mary Picard |
| Unclassified | Unclassified | Unclassified | SAR | 25 | 19b. TELEPHONE NUMBER (include area code) (301) 757-0674 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

## SUMMARY

The F/A-18A-D fleet has been experiencing cracked brackets on the right main landing gear (MLG) wheel well hydraulic 2A (HYD 2A) pressure supply line. Investigations revealed that hydraulic pressure spikes in the HYD 2A supply line may be a contributing factor to the bracket failure. Some bracket failures have led to HYD 2A supply line failures. F/A-18E/F testing determined that landing gear circuit breaker resets and improper gear retractions following an emergency gear extension caused pressure spikes. A suspected but unproven cause of pressure spikes is the first engine start of the day. For this test, a production F/A-18A-D landing gear control unit (LGCU) was modified at NADEP North Island to accept a restrictor within the emergency port of the valve. The Boeing and Northrop Grumman developed restrictors were designed to control emergency spool movement and eliminate pressure spikes in the HYD 2A supply line. Three restrictors were designed with increasing levels of restriction (2000, 5500, and 9000 lohm). The elimination of pressure spikes is expected to reduce or eliminate the hydraulic line bracket failures that have been occurring in the USN/USMC fleet and FMS aircraft.

The purpose of this test was to investigate causes of pressure spikes in the HYD 2A supply line to the MLG control unit and evaluate the use of a restrictor in the F/A-18A-D aircraft. Specifically:

a. To determine the magnitude of pressure spikes during improper gear retractions.

b. To determine the magnitude of pressure spikes during landing gear circuit breaker resets with the landing gear handle in the up and down positions.

c. To determine the magnitude and frequency of pressure spikes in the HYD 2A supply line during the first simulated engine start of the day.

d. To determine which restrictor effectively controlled emergency spool movement and reduced pressure spikes in the MLG HYD 2A supply line during improper gear retractions.

e. To ensure the selected restrictor did not adversely affect gear extension/retraction times on the ground and in flight when installed in both the main LGCU (MLGCU) and nose LGCU (NLGCU).

The entire evaluation consisted of three phases of ground tests and one phase of piggyback flight test and took place from 12 September 2000 through 28 March 2001. The 2000 lohm restrictor installed in the MLGCU effectively eliminated large magnitude pressure and vibration oscillations during improper gear retractions while not adversely affecting landing gear times. Recommend using the 2000 lohm restrictor in both the NLGCU and MLGCU to control pressure oscillations in the emergency and HYD 2A lines while reducing the number of different configuration LGCU's.

Contents

# INTRODUCTION

## BACKGROUND

1. The F/A-18A-D fleet has been experiencing cracked brackets on the right main landing gear (MLG) wheel well hydraulic 2A (HYD 2A) pressure supply line. Investigations revealed that hydraulic pressure spikes in the HYD 2A supply line may be a contributing factor to the bracket failure. The pressure spikes cause the HYD 2A line to move excessively (1/4 in.) which stresses the brackets, eventually leading to bracket failure. Additionally, hydraulic line preload may compound the problem. Some bracket failures have led to HYD 2A supply line failures. F/A-18E/F testing determined that landing gear circuit breaker resets and improper gear retractions following an emergency gear extension caused pressure spikes. A suspected but unproven cause of pressure spikes is the first engine start of the day. During hydraulic operation, air bubbles in the lines are compressed into the hydraulic fluid due to normal hydraulic fluid pressure. Overnight, while the aircraft hydraulic fluid is not pressurized for a significant amount of time, the air bubbles come out of solution creating air pockets. Then, during startup the next morning, the hydraulic system is pressurized when the engines reach 7% N2 but the main landing gear control unit (MLGCU) does not receive electrical power until 60% N2. Before power is applied to the MLGCU, hydraulic pressure is stopped at the MLGCU and both the gear up and gear down lines are ported to the return. Once the MLGCU receives power, the gear down solenoid is opened allowing HYD 2A supply pressure into the gear down lines and porting the gear up lines to return. The rapid shift in pressure and the fluid filling the air pockets by recompressing the air back into the hydraulic fluid, could result in significant pressure transients, vibrations, and strains in the hydraulic lines upstream of the MLGCU.

2. For this test, a production F/A-18A-D LGCU was modified at NADEP North Island to accept a restrictor in the emergency port. The Boeing and Northrop Grumman developed restrictors were designed to control emergency spool movement and eliminate pressure spikes in the HYD 2A supply line. Three restrictors were designed with increasing levels of restriction (2000, 5500, and 9000 lohm). The elimination of pressure spikes is expected to reduce or eliminate the hydraulic line bracket failures that have been occurring in the USN/USMC fleet and FMS aircraft.

3. NAVAIRSYSCOM (PMA-265) tasked NAWCAD Patuxent River, Maryland, to perform tests, in accordance with reference 1, to determine which, if any, restrictor effectively controls emergency spool movement and reduces pressure spikes in the HYD 2A supply line. Additionally, NAWCAD Patuxent River was tasked to investigate other potential causes of pressure spikes in the HYD 2A supply line.

## PURPOSE

4. The purpose of this test was to investigate causes of pressure spikes in the HYD 2A MLGCU supply line and evaluate the use of a restrictor in the MLGCU emergency port of the F/A-18A-D aircraft. Specifically:

a. To determine the magnitude of pressure spikes during improper gear retractions.

b. To determine the magnitude of pressure spikes during landing gear circuit breaker resets with the landing gear handle in the up and down positions.

c. To determine the magnitude and frequency of pressure spikes in the HYD 2A supply line during the first simulated engine start of the day.

d. To determine which restrictor effectively controlled emergency spool movement and reduced pressure spikes in the MLG HYD 2A supply line during improper gear retractions.

e. To ensure the selected restrictor did not adversely affect gear extension/retraction times on the ground and in flight when installed in both the MLGCU and nose LGCU (NLGCU).

SCOPE OF TESTS

5. The entire evaluation consisted of three phases of ground tests and one phase of piggyback flight tests and were broken down as follows:

a. Phase one ground evaluation – occurred from 12-21 September 2000 and consisted of 4 days of ground tests for approximately 30 hr. F/A-18A SD105 BuNo 163093, Lot 9, was the test aircraft. The evaluation was performed first using the production MLGCU, and then a modified control unit with 2000 and 5500 lohm restrictors, consecutively. The evaluation included a landing gear control handle configuration check, first simulated engine starts of the day, normal gear swings, emergency gear swings with and without a landing gear test control cable, and improper gear retractions following an emergency gear extension.

b. Phase two ground evaluation - occurred from 21 September-15 November 2000. The tests timed normal and emergency landing gear extensions/retractions with a 2000 lohm restrictor installed in the NLGCU. F/A-18A SD105 BuNo 163093, Lot 9, was the test aircraft.

c. Phase three ground evaluation - occurred on 13-14 March 2001. The test aircraft F/A-18D SD120 BuNo 163434, was a Lot 10 aircraft for the purposes of these tests. The ground tests evaluated normal and emergency extension/retraction times with a 2000 lohm restrictor installed in both the MLGCU and NLGCU.

d. Piggyback flight test evaluation – occurred from 12-28 March 2001 and consisted of six piggyback flights. The test aircraft F/A-18D SD120 BuNo 163434, was a Lot 10 aircraft for the purposes of these tests. The flight tests evaluated normal and emergency extension/retraction times in flight first with production NLGCU and MLGCU, then with a 2000 lohm restrictor installed in both the MLGCU and NLGCU.

INSTRUMENTATION

6. The phase one ground test evaluation used analog and MUX BUS instrumentation. Phase two and three ground tests and piggyback flight tests collected only MUX BUS data. Analog instrumentation, table 1, consisted of a pressure transducer in the emergency hydraulic return line (P/N 74A695906-1003) and HYD 2A supply line (P/N 74A695907-1003), and a triaxial accelerometer on the HYD 2A supply line. A special HYD 2A line was fabricated for the pressure tap to prevent modifying the production line. The modified HYD 2A line had a tee swaged into it off of which a line (4.75 in.) connected to the pressure transducer. The transducer was mounted to the test HYD 2A line near the LGCU using a clamp with a spacer. For the emergency line pressure transducer installation, the 90-deg elbow off of the MLGCU emergency port was replaced with a tee fitting from which a line (approximately 13 in. long) ran to the transducer. The transducer was mounted on a plate that was installed where the encoder/decoder normally is installed. Figure 1 shows the location of the instrumentation. The analog parameters were transmitted directly to an instrumentation van via cables. The analog parameters were monitored real-time on strip charts and recorded in instrumentation van. MUX BUS data were recorded on an onboard aircraft recorder.

Table 1: Analog Instrumentation for MLG Restrictor Ground Tests

| Parameter Name | Range | Parameter Type | Units | Parameter |
|---|---|---|---|---|
| H2ASPT | 0-10,000 | Analog Measurand | psig | HYD 2A Supply Line Pressure Transducer |
| EESLPT | 0-10,000 | Analog Measurand | psig | Emergency Extension Supply Line Pressure Transducer |
| H2ASAC | ±1,000 g's | Analog Measurand | g | HYD 2A Supply Line Accelerometer |

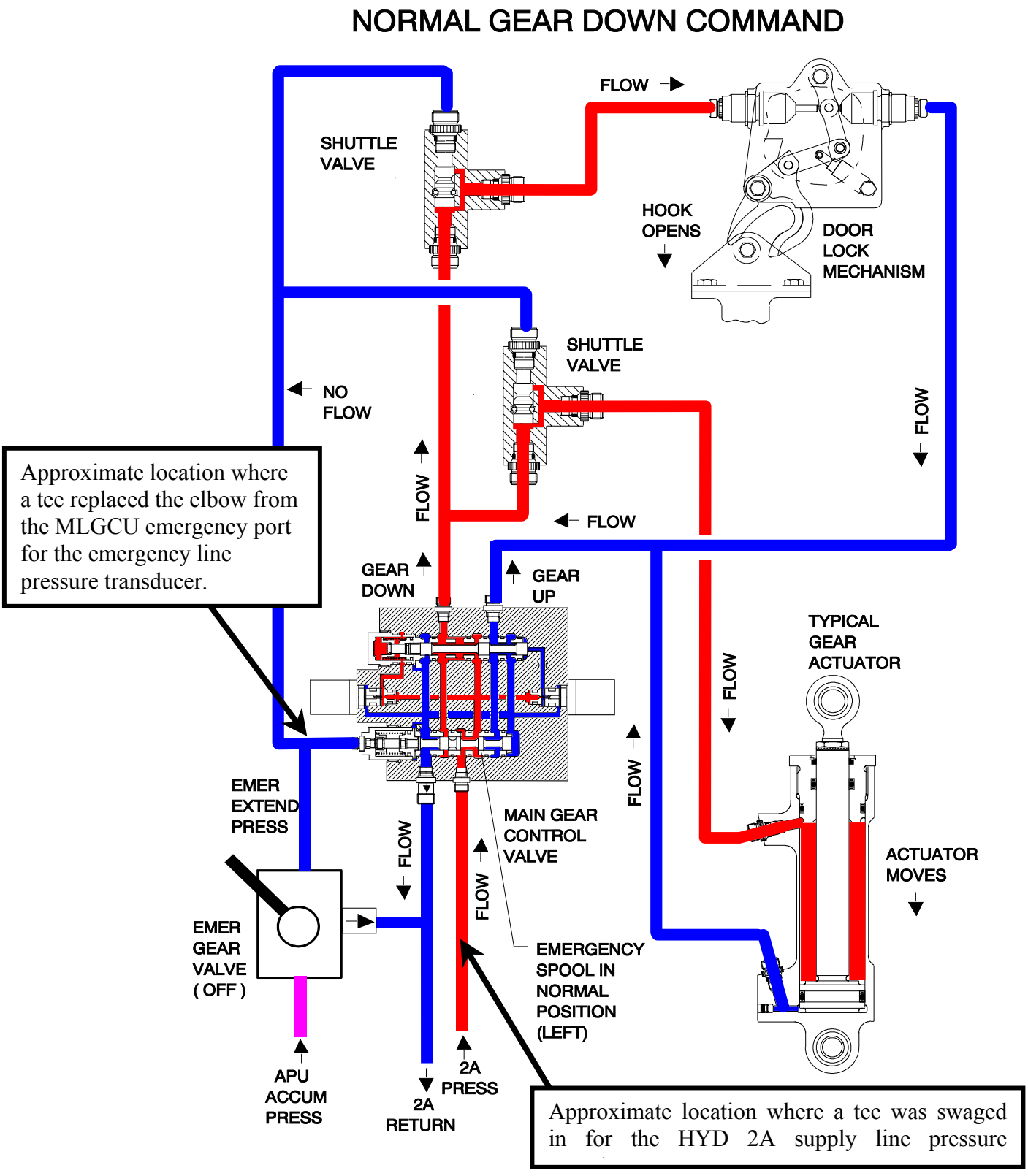


Figure 1: Location of Pressure Transducers in MLG Gear System

TEST CONFIGURATION

7. After each LGCU configuration change, the hydraulic system was bled, per maintenance procedures. For all ground tests, the aircraft was placed on jack stands. A hydraulic cart supplied hydraulic pressure and line power supplied aircraft electrical power. LGCU configurations for each phase of testing are as follows:

a. Phase One Ground Tests

(1) Production MLGCU and NLGCU.

(2) MLGCU (production control unit, P/N 0711322-009, with restrictor, as modified, P/N 0711322-152-1) with 2000 lohm restrictor (P/N JETA1875200D) and production NLGCU.

(3) MLGCU (production control unit, P/N 0711322-009, with restrictor, as modified, P/N 0711322-152-2) with 5500 lohm restrictor (P/N JETA1875550D) and production NLGCU.

b. Phase Two Ground Tests

(1) Production MLGCU and NLGCU (production control unit, P/N 0711322-009, with restrictor, as modified, P/N 0711322-152-1) with 2000 lohm restrictor (P/N JETA1875200D).

c. Phase Three Ground Tests

(1) Production MLGCU and NLGCU (P/N 0711322-011).

(2) 2000 lohm restrictor (P/N JETA1875200D) in both MLGCU and NLGCU (production P/N 0711322-011).

d. Piggyback Flight Tests

(1) Production MLGCU and NLGCU (P/N 0711322-011).

(2) 2000 lohm restrictor (P/N JETA1875200D) in both MLGCU and NLGCU (production P/N 0711322-011).

## DESCRIPTION OF TEST METHODS

### FIRST SIMULATED ENGINE START OF THE DAY

8. During a normal internal power (auxiliary power unit (APU)) engine start, hydraulic pressure reaches nominal levels before the control unit receives electrical power which allows the pressure spikes to occur as described in paragraph 1. In order to simulate an internal power engine start without having to start the engines, the following procedures were performed. The weight on wheels (WOW) box was connected and WOW selected. With the landing gear extended, the landing gear circuit breaker pulled. External electrical and hydraulic power were turned on and when hydraulic system pressure reached 3000 psi, the landing gear circuit breaker was pushed in to simulate electrical power coming on line at 60% N2.

### HANDLE CONFIGURATION CHECK

9. Two configurations of landing gear handles exist on the F/A-18A-D aircraft to actuate the emergency gear extension. One configuration required that the handle be rotated and pulled while the other configuration only required the handle be rotated. In order to determine which configuration the test aircraft had, the following procedures were used: With external electrical and hydraulic power operating, the forward cockpit landing (LDG) gear handle was raised and the landing gear and doors were allowed to close. The LDG gear control handle was rotated 90 deg clockwise. If the gear did not extend, the LDG gear control handle was the type that must be pulled to activate the emergency gear extension. If the gear did extend, then the LDG gear control handle was the type that did not need to be pulled to activate the emergency gear extension. The test aircraft (SD105) had the handle that was rotated and pulled to active the emergency gear extension.

### NORMAL GEAR EXTENSION/RETRACTIONS

10. Normal gear extensions/retractions were timed to ensure the restrictors did not adversely affect gear extensions and retractions. Normal gear extensions were timed by noting how long it took the gear to fully extend starting from when the LDG gear handle was lowered to when all three landing gear position lights in the handle were green. The limits, per reference 2, were as follows: NLG doors open and NLG extends in 8 sec maximum and MLG doors open and MLG extends in 7 sec maximum. Normal gear retractions were timed starting from when the LDG gear handle was raised and ending when the landing gear position lights extinguished. The limit, per reference 2, for gear retraction was 7 sec maximum.

### EMERGENCY GEAR EXTENSION/RETRACTIONS

11. Emergency gear extension/retractions were performed to ensure system characteristics were satisfactory with the restrictors installed. The following procedures were used: with the landing gear circuit breaker open, the forward cockpit LDG gear handle was selected to down (landing gear warning light illuminated). Then, the forward cockpit LDG gear handle was rotated 90 deg clockwise and pulled to the detent. Time to full extension was recorded. The limit, per reference 2, for emergency gear extension was 30 sec maximum. Time started from when the

LDG gear handle was pulled and ceased when all three landing gear position lights in the LDG gear handle were green. The APU/emergency brake accumulator was then recharged by holding the HYD ISO SW in "ORIDE" for 10 sec or until the "APU ACCUM" caution was removed (gage read between 2750 to 3250 psi and the needle stopped moving.) The emergency landing gear control was reset, followed by the landing gear circuit breaker. The LDG gear handle was not raised (landing gear retracted) until at least 5 sec after the circuit breaker and handle was reset.

SIMULATED FAILED MAIN LANDING GEAR CONTROL UNIT

12. To ensure that the emergency gear extension function was satisfactory when an MLGCU with a restrictor failed (blocked), the following procedures were performed: using the procedures defined in reference 3, a landing gear control test cable was used to simulate a failed MLGCU. External electrical and hydraulic power was disconnected. The landing gear circuit breaker was pulled and maintenance installed the landing gear control test cable assembly (3221as171-1) per reference 3. On the landing gear control test cable assembly, the gear up/norm switch was set to gear up. External electrical and hydraulic power was applied per reference 3. The emergency gear extension procedures were performed. After gear extension, the test cable was removed, following maintenance procedures in reference 3.

IMPROPER GEAR RETRACTION

13. To determine if the restrictor eliminated emergency spool movement and pressure spikes in the HYD 2A supply line, improper gear retractions were performed as follows: The landing gear circuit breaker was pulled. Then, with the forward cockpit LDG gear handle in the up position, the handle was rotated 90 deg clockwise and pulled to the detent to perform an emergency gear extension (normal procedures had the LDG gear handle in the down position for this step). When all three landing gear position lights in the LDG gear handle were green, the APU/emergency brake accumulator was recharged by holding the HYD ISO SW was in "ORIDE" for 10 sec or until the "APU ACCUM" caution was removed (gage read between 2750 and 3250 psi and the needle stopped moving). The emergency landing gear control function was reset by pushing in the forward cockpit LDG gear handle and rotating it 90 deg counterclockwise. The landing gear circuit breaker was then reset and the gear immediately retracted. Proper procedures require that the landing gear not be retracted until 5 sec after the circuit breaker is reset.

LESSONS LEARNED

14. Lessons learned were identified in the instrumentation area. The triaxial accelerometer came off the HYD 2A line twice during improper gear retractions. A change in glue to EA9394 AS9277009 Hysol Aerospace Products manufactured by Dexter Aerospace Materials Division, NSN: 8040011695304, was successful in keeping it attached. Additionally, the calibration of the accelerometer was too low initially at 500 g's and was recalibrated to 1,000 g's.

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# RESULTS AND EVALUATION

## GENERAL

15. Data for these tests consisted of pressures, accelerations, and gear extension/retraction times. Timing was performed by ground observers and by the crew in the cockpit both utilizing stop watches. The ground observer timed the extensions/retractions from the start of gear movement to when the gear had stopped moving. The cockpit timing was performed by starting when the gear handle was moved until the lights extinguished (extension) or lit up (retraction). The two different methods resulted in significant timing difference for the same test points. Only the ground observer data are presented and were used to draw conclusions and recommendations for the ground testing since it was more consistent and had a larger sample size. However, the cockpit data trends were similar to the ground observer data. For the piggyback flight tests only, cockpit data were obtained. Note that the limits for gear extensions and retractions in paragraph 10 uses the cockpit observer for timing. Some of the ground observer data does not meet the limits; however, all of the cockpit acquired data were within limits for all test points. Subsequent paragraphs discuss the results, conclusions, and recommendations based upon each of the specific test purposes.

## EMERGENCY SPOOL MOVEMENT AND PRESSURE SPIKE REDUCTION

### IMPROPER GEAR RETRACTION AFTER EMERGENCY EXTENSION

16. In order to baseline the system, improper gear retractions after emergency extensions were performed on the ground with a production MLGCU and NLGCU. During improper gear retractions after an emergency extension, the gear chattered loudly and violently. Pressures in the emergency line oscillated from about 50 to 1300 psig with peaks as high as 2200 psig. At the same time, pressures in the HYD 2A line oscillated from 0 to 8000 psig with peaks as high as 8900 psig. The chatter lasted approximately 1 sec. To an observer, it was an obvious, loud, and violent reaction during the gear retraction. Vibration levels in the y-direction exceeded the ±1,000 g calibration of the accelerometer. Values were estimated to be +500/-600 g's in the x-direction, over ±1,000 g's in the y-direction, and +700/-650 g's in the z-direction. Improper gear retractions after emergency extensions cause large pressure spikes that are a significant contributor to line movement and subsequent bracket failure.

### RESTRICTORS EFFECTS ON PRESSURE SPIKE REDUCTIONS

17. Three restrictors were available to determine which eliminated or reduced emergency spool movement and pressure spikes in the HYD 2A line. After production baseline tests were completed with no restrictors, a 2000 lohm restrictor was installed in the emergency port of the MLGCU and the improper gear retraction procedures were repeated. In this configuration, the pressure spikes were essentially eliminated. No chatter or violent shaking of the gear was observed. In the emergency line, the pressure ranged from 50-150 psig. In the HYD 2A line, the pressure levels fluctuated between 2700-2900 psig with some stray peaks 200-600 psig greater than the quasi steady state levels. There were essentially no vibrations of the HYD 2A line during the gear retraction. Only a small peak (approximately 160 g's in all axes) occurred when

the doors closed, which was the same with the production configuration. To determine if any additional benefits would be gained by a greater restriction, the 5500 lohm restrictor was installed. The only difference between the 5500 and 2000 lohm restrictor on the HYD 2A pressure levels was a reduction in the amount of pressure fluctuations. With the 5500 lohm restrictor installed in the MLGCU, the pressure levels were between 2800-2900 psig with no stray peaks. The emergency line pressure were the same with the 5500 and 2000 lohm restrictor, with levels at 50-150 psig. Vibrations were also eliminated with the 5500 lohm restrictor except for a small peak (approximately 160 g's in all axes) when the doors were closed. The 2000 lohm restrictor reduced the pressure oscillations from over an 8000 psig range down to a 200 psig range and eliminated the vibration of the HYD 2A line during an improper gear retraction. The 5500 lohm restrictor reduced the pressure oscillations to a 100 psig range. The 2000 lohm restrictor effectively eliminated the large magnitude pressure and vibration oscillations during an improper gear retraction. The 5500 lohm restrictor only marginally improved upon the performance of the 2000 lohm restrictor in reducing pressure oscillations, while no additional benefit was gained in the emergency line, or with vibrations in the HYD 2A line. Recommend using the 2000 lohm restrictor in the MLGCU to significantly reduce pressure oscillations in the emergency and HYD 2A lines and eliminate movement of the HYD 2A line during improper gear retractions.

## GEAR EXTENSION/RETRACTION TIMES

### GENERAL

18. Production gear retraction/extension times were compared to retraction/extension times with restrictors installed. The following configurations are discussed in subsequent paragraphs: the 2000 and 5500 lohm restrictors in the MLGCU, the 2000 lohm restrictor in the NLGCU, and ground and flight tests with 2000 lohm restrictors in the NLGCU and MLGCU.

### GROUND TESTS – PHASE ONE

19. For this phase, 2000 and 5500 lohm restrictors were tested in the MLGCU. Since both the 2000 and 5500 lohm restrictors were effective in removing the pressure spikes, gear extension and retraction times were compared to production times determine if any degradation was observed due to the increased flow restriction. Table 2 summarizes gear extension and retraction times for the three configurations. No significant increase in extension/retraction times occurs with either the 2000 or 5500 lohm restrictor as compared to the production configuration.

Table 2: Gear Extension and Retraction Times for Ground Tests - Phase One[1]

| Gear Cycle Type[2] | LGCU Configuration | | |
|---|---|---|---|
| | MLGCU and NLGCU: Production (No Restrictor) Time (sec)[3][4] | MLGCU: 2000 lohm Restrictor NLGCU: Production Time (sec)[3] | MLGCU: 5500 lohm Restrictor NLGCU: Production Time (sec)[3] |
| NLG Normal Extension | 9 | 9 | 9 |
| NLG Normal Retraction | 7 | 7 | 7 |
| NLG Emergency Extension | 12 | 13 | 13 |
| NLG Improper Emergency Extension | 13 | 13 | 13 |
| NLG Test Cable Extension | 13 | 13 | 14 |
| MLG Normal Extension | 7 | 7 | 7 |
| MLG Normal Retraction | 8 | 9 | 9 |
| MLG Emergency Extension | 7 | 7 | 7 |
| MLG Improper Emergency Extension | 7 | 8 | 7 |
| MLG Test Cable Extension | 7 | 7 | 7 |

NOTES: (1) These tests were performed on SD105 BuNo 163093.
(2) NLG – nose landing gear, MLG – main landing gear.
(3) All times are from a ground observer and are averages that have been rounded to the nearest whole number.
(4) The production configuration was the baseline and should only be used for comparison with tests on the same aircraft since extension and retraction times vary from aircraft to aircraft.

GROUND TESTS – PHASE TWO

20. In order to determine if a LGCU with restrictor could also be used in the NLGCU (same part number as the MLGCU), a 2000 lohm restrictor was tested in the NLGCU. The modified LGCU was installed in place of the production NLGCU. Tests were performed to determine if the 2000 lohm restrictor caused a significant increase in gear extension/retraction times. Table 3 summarizes the results with the modified NLGCU. The production data for these tests are shown separately rather than averaged with phase one since a different ground observer recorded the data. Results show that there is no increase in gear extension/retraction times with the 2000 lohm restrictor in the NLGCU. The 2000 lohm restrictor installed in the NLGCU does not cause any adverse effects on gear extension/restriction times.

Table 3: Gear Extension and Retraction Times for Ground Tests - Phase Two[1]

| Gear Cycle Type[2] | LGCU Configuration | |
|---|---|---|
| | MLGCU and NLGCU: Production (No Restrictor) Time (sec)[3][4] | MLGCU: Production NLGCU: 2000 lohm Restrictor Time (sec)[3] |
| NLG Normal Extension | 7 | 7 |
| NLG Normal Retraction | 5 | 5 |
| NLG Emergency Extension | 10 | 10 |
| MLG Normal Extension | 5 | 5 |
| MLG Normal Retraction | 6 | 6 |
| MLG Emergency Extension | 6 | 6 |

NOTES: (1) These tests were performed on SD105 BuNo 163093.
(2) NLG – nose landing gear, MLG – main landing gear.
(3) All times are from a ground observer and are averages that have been rounded to the nearest whole number.
(4) The production configuration was the baseline and should only be used for comparison with tests on the same aircraft since extension and retraction times vary from aircraft to aircraft.

## GROUND TESTS - PHASE THREE AND FLIGHT TESTS

21. For this phase, 2000 lohm restrictors were installed in both the NLGCU and MLGCU. A different aircraft, SD120 BuNo 163434, was used for these tests due to availability. Table 4 summarizes the ground test results with production (baseline) NLGCU and MLGCU and with 2000 lohm restrictors in both the MLGCU and NLGCU. Table 5 summarizes the flight test results with production (baseline) NLGCU and MLGCU and with 2000 lohm restrictors in both the MLGCU and NLGCU. Results showed that the only change in gear cycle times during ground tests was during the MLG normal retraction which increased by a second with the restrictors installed. Flight test results show that there was no increase in gear extension/retraction times in flight with the 2000 lohm restrictor in the NLGCU and MLGCU. The 2000 lohm restrictor installed in the NLGCU and MLGCU do not cause any significant adverse effects on gear extension/restriction times on the ground or in flight. Recommend using the 2000 lohm restrictor in both the NLGCU and MLGCU to reduce the number of LGCU configurations.

Table 4: Gear Extension and Retraction Times for Ground Tests - Phase Three[1]

| Gear Cycle Type[2] | LGCU Configuration | |
|---|---|---|
| | MLGCU and NLGCU: Production (No Restrictor) Time (sec)[3][4] | MLGCU and NLGCU: 2000 lohm Restrictors Time (sec)[3] |
| NLG Normal Extension | 7 | 7 |
| NLG Normal Retraction | 5 | 5 |
| NLG Emergency Extension | 10 | 10 |
| MLG Normal Extension | 5 | 5 |
| MLG Normal Retraction | 6 | 7 |
| MLG Emergency Extension | 6 | 6 |

NOTES: (1) These tests were performed on SD120 BuNo 163434.
(2) NLG – nose landing gear, MLG – main landing gear.
(3) All times are from a ground observer and are averages that have been rounded to the nearest whole number.
(4) The production configuration was the baseline and should only be used for comparison with tests on the same aircraft since extension and retraction times vary from aircraft to aircraft.

Table 5: Gear Extension and Retraction Times for Flight Tests[1]

| Gear Cycle Type | LGCU Configuration | |
|---|---|---|
| | MLGCU and NLGCU: Production (No Restrictor) Time (sec)[2][3] | MLGCU and NLGCU: 2000 lohm Restrictors Time (sec)[2] |
| Normal Extension | 6 | 6 |
| Normal Retraction | 7 | 7 |
| Emergency Extension | 9 | 9 |
| Normal Extension after Emergency Extension | 7 | 7 |

NOTES: (1) These tests were performed on SD120 BuNo 163434.
(2) All times are from a cockpit observer and are averages that have be rounded to the nearest whole number.
(3) The production configuration was the baseline and should only be used for comparison with tests on the same aircraft since extension and retraction times vary from aircraft to aircraft.

CIRCUIT BREAKER RESETS

22. Data were obtained during circuit breaker resets with both the gear handle up and down to determine if pressure changes occur. With the production configuration, MLGCU HYD 2A pressure spikes averaged 4000-4300 psig with a peak of 5600 psig. Similar pressures were recorded with 2000 lohm restrictor with average pressures of 4200 to 4300 psig. The 5500 lohm restrictor appeared to have a small reduction in pressure with average pressures of 4000-4200 psig. The reduction of pressure with the 5500 lohm restrictor was not significant compared to the almost complete elimination of pressure oscillations during the improper gear retraction (oscillations of 0-8000 psig to 100-200 psig). A decrease of 100 psig during the circuit breaker reset was more likely statistical variation rather than an effect of the restrictor. Vibrations of the HYD 2A line during the circuit breaker resets were similar to when the doors close, approximately 160 g's in all directions. The duration of the pressure spike during the circuit breaker reset is much shorter (approximately 0.1 sec) than during the improper gear retraction (1 sec). Since the duration and magnitude of the pressure spikes observed during the circuit breaker reset is significantly less than those of the improper gear retraction, the circuit breaker reset is not likely a significant contributor to the HYD 2A supply line failures. The 2000 and 5500 lohm restrictors, installed in the MLGCU, eliminated the short duration HYD 2A supply line pressure spike during a circuit breaker reset but did not reduce overall pressure levels significantly.

FIRST SIMULATED ENGINE START OF THE DAY

23. Pressure data were analyzed during test points that simulated first engine starts of the day. Neither pressure spikes nor vibrations were evident these test points. First engine starts of the day do not produce pressure or vibrations of the HYD 2A supply line that contribute to the line failures.

# CONCLUSIONS

## GENERAL

24. Improper gear retractions are the most significant contributor toward HYD 2A bracket failures and the 2000 lohm restrictor installed in the MLGCU effectively eliminates the large pressure and vibration oscillations without adversely affecting gear extension or retraction times.

## SPECIFIC

25. Improper gear retractions after emergency extensions cause large pressure spikes that are a significant contributor to line movement and subsequent bracket failure (paragraph 16).

26. The 2000 lohm restrictor effectively eliminated the large magnitude pressure and vibration oscillations during an improper gear retraction (paragraph 17).

27. The 5500 lohm restrictor only marginally improved upon the performance of the 2000 lohm restrictor in reducing pressure oscillations, while no additional benefit was gained in the emergency line, or with vibrations in the HYD 2A line (paragraph 17).

28. No significant increase in extension/retraction times occurs with either the 2000 or 5500 lohm restrictor in the MLGCU as compared to the production configuration (paragraph 19).

29. The 2000 lohm restrictor installed in the NLGCU does not cause any adverse effects on gear extension/restriction times (paragraph 20).

30. The 2000 lohm restrictor installed in the NLGCU and MLGCU do not cause any significant adverse effects on gear extension/restriction times on the ground or in flight (paragraph 21).

31. Since the duration and magnitude of the pressure spikes observed during the circuit breaker reset is significantly less than those of the improper gear retraction, the circuit breaker reset is not likely a significant contributor to the HYD 2A supply line failures (paragraph 22).

32. The 2000 and 5500 lohm restrictors, installed in the MLGCU, eliminated the short duration HYD 2A supply line pressure spike during a circuit breaker reset but did not reduce overall pressure levels significantly (paragraph 22).

33. First engine starts of the day do not produce pressure or vibrations of the HYD 2 A supply line that contribute to the line failures (paragraph 23).

# RECOMMENDATIONS

## GENERAL

34. Recommend using the 2000 lohm restrictor in both the NLGCU and MLGCU to control pressure oscillations in the emergency and HYD 2A lines while reducing the number of different configuration LGCU's.

## SPECIFIC

35. Use the 2000 lohm restrictor in the MLGCU to significantly reduce pressure oscillations in the emergency and HYD 2A lines and eliminate movement of the HYD 2A line during improper gear retractions (paragraph 17).

36. Use the 2000 lohm restrictor in both the NLGCU and MLGCU to reduce the number of LGCU configurations (paragraph 21).

# REFERENCES

1. Air Vehicle Work Unit 44NP4 Document No. N0001900WXZZ3KL, of 12 Oct 1999.

2. NATOPS Flight Manual, Navy Model F/A-18A/B/C/D 161353 and Up Aircraft, A1-F18AC-NFM-000, of 15 Jan 1997 with Change 5 of 1 Sep 1999.

3. A1-F18AC-130-200, Organizational Maintenance Testing and Troubleshooting Landing Gear Systems Navy Model F/A-18A/B/C/D, Work Package 003 00 Tables 1 and 2, of 15 Jun 1998.

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